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Tests of Flexural Strength of Concrete

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TESTS OF FLEXURAL STRENGTH OF CONCRETE

BY

FRANK STANLEY MUSSER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1909

1909
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UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK STANLEY MUSSER

ENTITLED TESTS OF FLEXURAL STRENGTH OF CONCRETE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

D. A. Abrams

A. N. Talbot

Instructor in Charge

APPROVED: John P. Brooks

HEAD OF DEPARTMENT OF Civil Engineering

247481

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MANUSCRIPT

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PART 1.

INTRODUCTION

The strength of a beam of plain concrete is limited by the tensile strength of the concrete at the place of greatest stress which is at its lowest surface when vertically loaded.

The value of this "fiber" stress or modulus of rupture is of less importance than the crushing strength on account of the brittleness of concrete in tension, therefore it is not economical to construct beams or girders without metal reinforcement.

Very little is known regarding the tensile strength of plain concrete when used in any test piece because of the small deformation before rupture. Since concrete beams can be broken with less powerful and less expensive apparatus than crushing specimens, this form of specimen is convenient for comparing the relative strengths of different mixtures or different materials. Concrete is subject to great variations in its properties owing to the wide variation in the character and proportion of its ingredients and preparation. Therefore it is especially important that the concrete be of uniform quality and free from voids which can be eliminated only be careful mixing. In all the following tests skilled workmen were employed and all materials were carefully selected. Tests were made of about 150 small beams 6 by 8 in. in cross section and 5 ft. 4 in. long, at the University of Illinois under the direction of the Engineering Experiment Station between March 1 and June 1, 1909.

The beams tested for this thesis were made at the same time as larger beams and footings, of the same reference number, described in other theses on reinforced concrete presented in the College of Engineering of the University of Illinois, June, 1909.

PART 2.

THEORY AND AVAILABLE DATA.

The following nomenclature is used in calculating the modulus of rupture by the formula $\frac{M}{S} = \frac{I}{c}$ where

M = bending moment due to load

S = modulus of rupture

I = moment of inertia of section

c = distance from neutral axis to extreme fiber.

A sample calculation is given for a load of 4000 lb. on a 3-ft. span. One cubic foot of concrete is taken as weighing 150 pounds. The moment of a uniformly loaded beam is taken as 1/8 Wl, where

W = 150 lb. = the weight of the beam

l = length of beam = 36 in.

moment = 675 lb. in.

$I = 1/12\ bd^3 = 256$

$c = 1/2\ d = 4$ in.

$S = Mc/I$ = 10.5 lb. per sq. in., the stress due to the weight of beam.

The beam was loaded at the 1/3 points.

M = 24 000 lb. in.

s = 380 lb. per sq. in.

S = 380 + 10.5 = 390.5 lb. per sq. in.

= modulus of rupture of concrete.

TABLE 1.

Modulus of Rupture, pounds per square inch

for different mixtures.

Mixture by Volume.	Age at Test, Days						
	7	28	56	84	133	182	273
1-2-3	95	145	215	266	301	303	320
1-2½-5	37	144	165	194	268	236	256
1-3-5		88	129	176	191	214	214
1-2½-6		81	130	156	193	199	212
1-3-7	37	113	154	187	216	243	263
1-2-4	113	202	271				

Table 1 is taken from Prof. I. O. Baker's "A Treatise on Masonry Construction" giving results of tests by Mr. A. F.Bruce.

The beams were 4 by 4 in. by 30 in. long. The aggregate was generally sandstone but gravel and broken stone were also used. In each case the voids in the sand were filled with cement and those in the aggregate with mortar.

It is seen that the results in the last line are proportionally higher than those in the remainder of the table. This is probably due to the fact that the tests of the first four lines were made with natural sand and stone while in the last test crushed stone was used. It is also seen that the strength of concrete increases with age and that the richer concrete has the greatest modulus of rupture. Up to about 60 or 80 days the concrete increases in strength very rapidly. After that a more gradual increase occurs for an indefinite period.

Table 2 also shows that the modulus of rupture increases with the richness of the concrete. It is taken from Bulletin No. 14 of the University of Illinois Engineering Experiment Station.

Table 2.

Tests of Plain Concrete Beams

8 x 11 in. x 13 ft.

Span = 12 ft.

Beam No.	Kind of Concrete	Age at Test days		Modulus of Rupture lb. per sq. in.
64	1-3-6	58		357
65	1-3-6	59		366
			Av.	362
66	1-2-4	59		375

Table 3 shows some conclusions taken from "A Treatise on Concrete" by Taylor and Thompson, p. 272, which shows the relation of the strengths of broken stone and gravel concrete with equal voids. The experiments were made by Candot.

Table 3.

Ratio of Strength of Broken Stone Concrete to Gravel Concrete.

Age days	Ratio of Strength
7	1.3
30	1.26
180	1.18

Table 4 is taken from a series of tests made during the year 1901 by Wm. B. Fuller, C.E., at Little Falls, N. J. on beams 6 by 6 in. by 72 in. long, with spans of 30 and 60 in. All beams were made with Atlas portland cement, river silica sand, and crusher run trap rock.

Table 4.

Proportions by Weight	Age days	Modulus of Rupture lb. per sq. in.
1-1-2	33	710
1-2-4	33	439
1-3-6	33	226
1-4-8	34	157

The above values are much higher than have been found in this thesis but the conditions of these tests were quite different, as the aggregate was of different kinds of stone and sand. Each of the above values is an average of six tests.

Table 5.

Variations in Quantity of Mortar.

Amount of Mortar used as percent of loose stone.	Modulus of Rupture lb. per sq. in.	Age at test	Number of Tests made
31	247	1 year	1
38	284	"	2
47	350	"	2
60	346	"	2

Table 5 shows that the ideal mixture should contain about 47% mortar. The first line of the table shows that the voids of the stone were not entirely filled with mortar when 31% mortar was used. The ideal mixture would require a great deal of labor to fill all the voids and the cost of labor would more than offset the amount of money saved in cement. This table was taken from Sabin's "Cement and Concrete."

Table 6.

Value of Thorough Mixing

Mixing of Concrete	No. Tests	Modulus of Rupture	Age
Turned once and back	2	290	1 year
Turned twice and back	2	294	"
Turned three times and back	2	306	"
Turned four times and back	2	328	"

Table 6 is given to show a comparison of the strength of concrete with different numbers of turnings. The variation of strength is about 20%, which would more than offset the cost of labor in mixing. The table plainly shows an increase in strength for an increase of thorough mixing.

PART 3.

MATERIAL, TEST-PIECES, AND METHOD OF TESTING.

STONE.

The stone used was Kankakee limestone, ordered screened through a 1-in. screen and over a $\frac{1}{4}$-in. screen. The stone weighed 86 lb. per cu. ft. and contained 48.5% voids, as determined from three samples.

Table 7 gives the proportions of the sizes as determined from 22 samples taken at different times throughout the year.

Table 7.

Fineness Tests of Stone.

Size of Mesh in inches	Per cent passing
1 in. = 1.000 in.	100
$\frac{3}{4}$ in. = .750 in.	87.0
$\frac{1}{2}$ in. = .500 in.	46.4
3/8 in. = .375 in.	28.9
No. 3 = .174 in.	13.7
No. 5 = .091 in.	1.76
No.10 = .066 in.	0.94

Table 7a

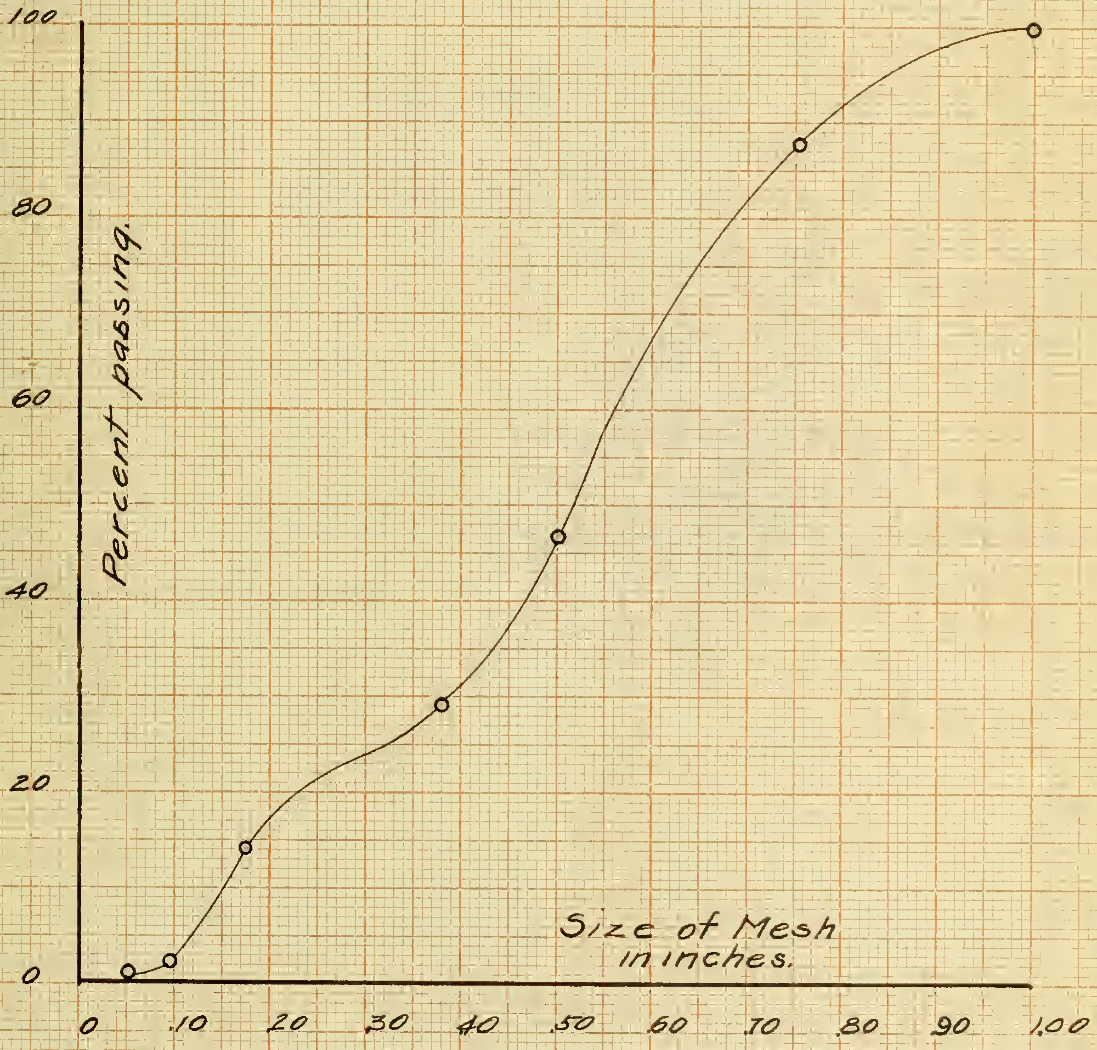
Void Tests of Stone

Weight of Box and stone. lb.	Per cent voids
83.0	50
172.6	45.8
162.5	49.7
Av.	48.5

PLATE I

DIAGRAM
showing
SIZE of STONE

Relation between percent passing and size of square mesh in inches.



U. OF I. S. S. FORM 3

Plate 1 is a curve showing the relation between the size of mesh in inches and the percent of stone passing through. In the determination of voids the material was poured slowly into the water so that no air remained.

SAND.

The sand used throughout these experiments was obtained from near the Wabash river at Attica, Indiana. The following three tests show that it contains an average of 46.5% voids.

Void Tests of Sand

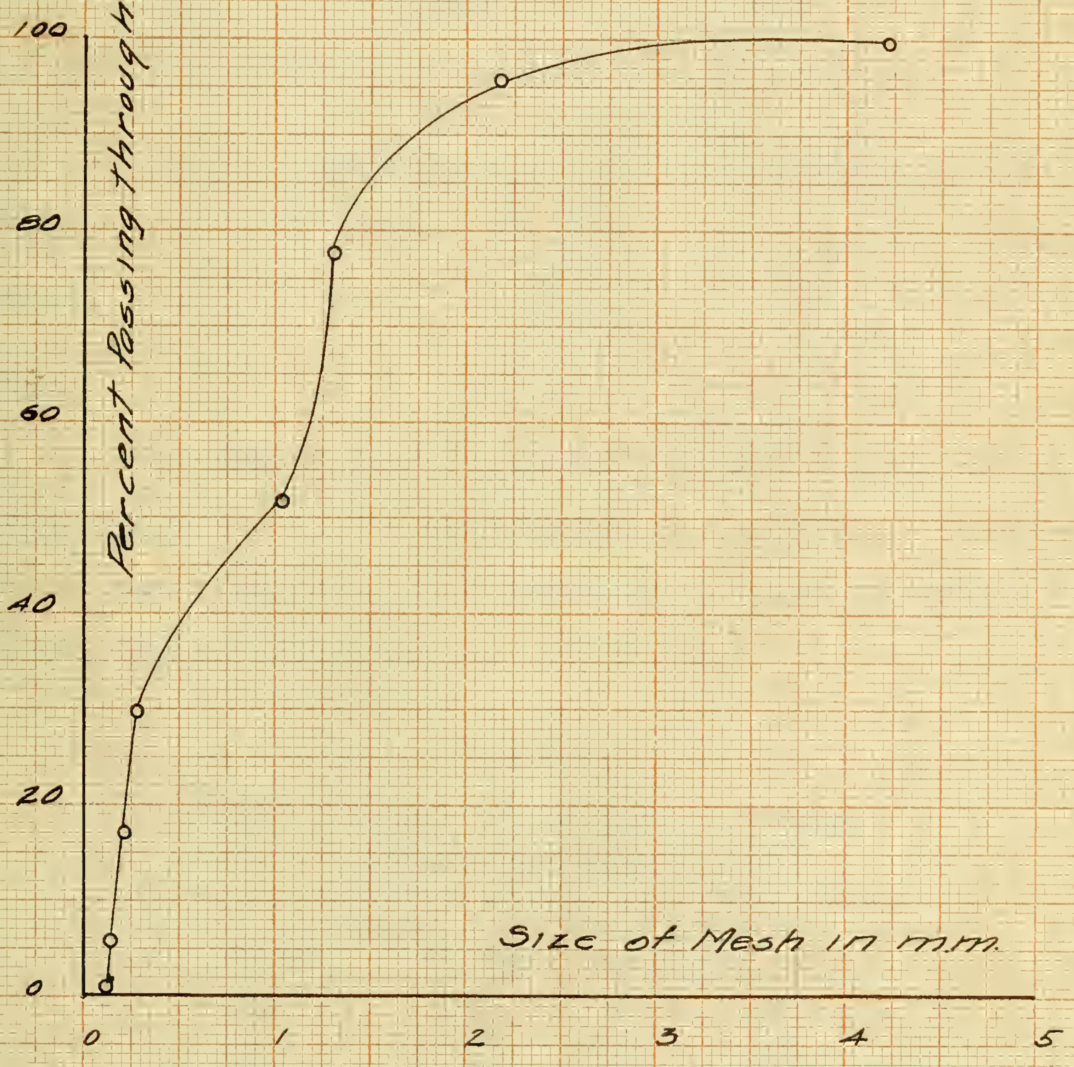
Weight of Box and sand.	Per cent voids
99.8	46.7
184.4	46.1
186.0	46.8
Av.	46.5

Table 8 shows the proportion of sizes as determined from 18 samples of sand.

PLATE 2.

DIAGRAM for FINENESS of SAND

Showing Relation Between Percent Passing through and size of Mesh in m.m.



U. OF S. S. FORM 3

Table 8.

Mechanical Analysis of Sand.

Sieve No.	Size in mm.	Percent Passing.
3	4.417	99.7
5	2.320	95.9
10	1.690	77.5
12	–	70.3
16	1.080	51.1
18	0.684	29.2
30	0.490	16.9
40	0.324	5.8
50	–	3.1
74	0.225	0.8
150	–	–

Plate 2 shows the curve for the fineness of sand, giving the relation between the size of mesh and the percent passing.

CEMENT.

The cement used in these tests was Chicago AA portland cement, purchased in the open market at Champaign, Illinois. Table 9 shows the results of tests made at the University of Illinois Cement Laboratory on this cement.

Table 9.

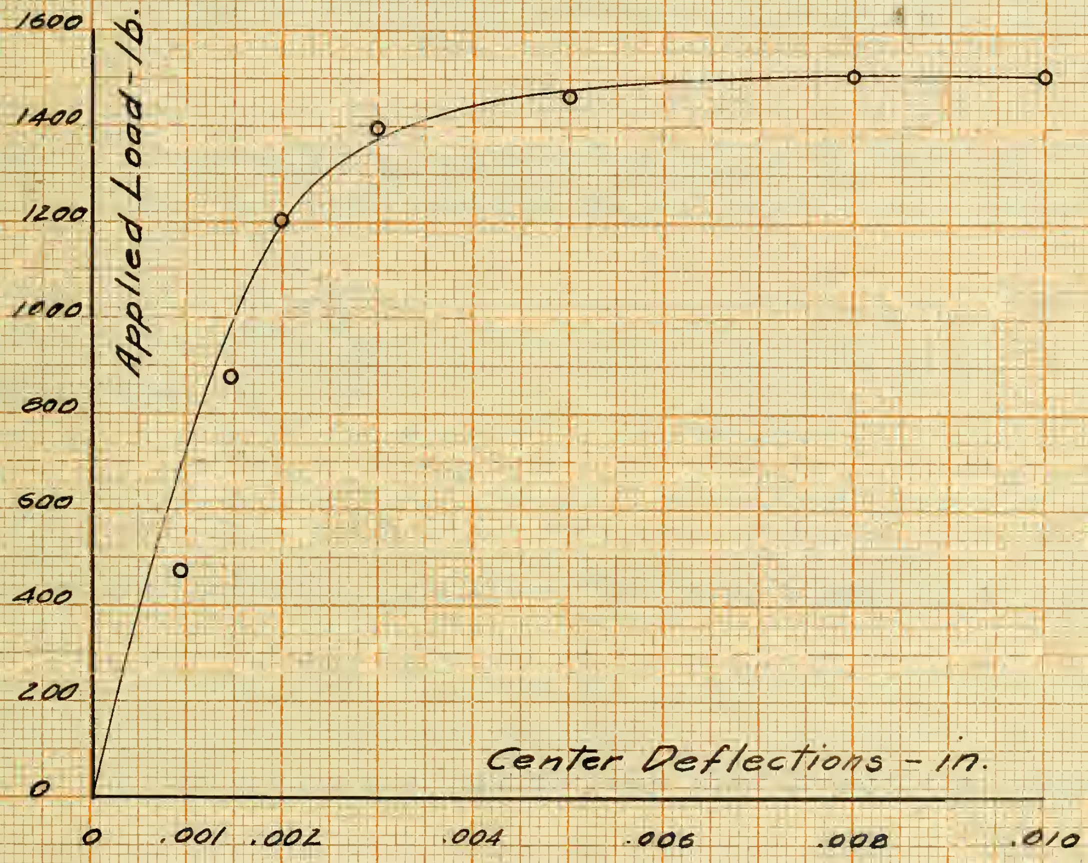
Tensile Strength of Chicago AA Cement pounds per square inch

	Neat		1–3 Mixture	
	7 day	28 day	7 day	28 day
	742	205	783	270
	716	232	807	306
	725	176	768	254
		288		333
Av.	727	225	786	291

PLATE 3

LOAD-DEFLECTION DIAGRAM for PLAIN CONCRETE BEAM Nº 1412

$1-2\frac{1}{2}-5$ --- 60 days.



The tests in Table 9 were made from briquettes of the form recommended by the Committee of the American Society of Civil Engineers.

The briquettes were covered with a damp cloth until they had set. After this they were stored in water until tested.

Table 10 is given from Bulletin No. 29 of the University of Illinois for average values of cement tests for the years 1907 and 1908, and were made with standard Ottowa sand. Each value is an average of 55 briquettes.

Table 10.

Cement Tests for Tensile Strength of Briquettes.

	Neat		1-3 mixture	
	7 day	28 day	7 day	28 day
1907	783	201	864	258
1908	692	188	788	287

TEST PIECES.

The beams tested were 6 in. wide by 8 in. deep and 3 ft. 4 in. long. The beams were made in wooden forms of white pine bolted securely together. The forms rested on a piece of building paper placed directly on the concrete floor of the cement laboratory.

The mixing was done by hand with shovels. Experienced workmen did all the work of making the test pieces. The sand and cement were poured on the sheet iron mixing board and mixed

until the color was uniform throughout. The dampened stone was then added and the mass turned twice, after which sufficient water was added to make a fairly wet mixture. Materials were measured in loose volume and afterwards weighed as a check. The aggregate was added in 3-in. layers, then thoroughly tamped and each beam was left in the form 7 days, being sprinkled each day during this time. After this, they were stored at the laboratory where the temperature ranged from 60° to 70° F.

TESTS OF BEAMS.

The beams were tested on a 100 000-lb. Olsen testing machine with a speed of .02 in. per minute and on a Riehle testing machine with a speed of .05 in. per minute.

The beams were placed in the machine as shown in Fig. I.

In all cases a piece of rubber belting was placed between the beam and the contact points when loaded. This acted as a cushion and decreased the rate of application of the load.

PART 4.

DISCUSSION.

Table 11 gives the average modulus of rupture for different mixtures and age at test.

Table 11.

Modulus of Rupture.

pounds per square inch for different mixtures.

Mixture by Volume.	Average Values Age of Test, Days. 50	60	70	80	90
1-1-2		370			
1-1½-3		359	366		396
1-2-4	327	341	301	296	384
1-2½-5	231	290	260	300	336
1-3-6		282	240	228	
1-4-8	151				
1-5-10	63				

The above table (No. 11) shows a gradual increase from about 60 days to 90 days. It is seen that the beams have gained most of their strength in 60 days; from then on the rate of increase is quite a considerable less. In all cases the richer mixtures of concrete show greater moduli of rupture.

It is noticed that the 1-4-8 and 1-5-10 mixtures are very weak.

Comparing Table 11 with Table 1 it is seen that in most cases of like mixtures Table 11 shows higher values for the same age. Taking a 1-2½-5 mixture from Table 1 and comparing it with a 1-2½-5 mixture from this thesis shown in Table 11 it

is seen that both tests of Table 11 have higher moduli of rupture than tests of Table 1.

Table 12.

Modulus of Rupture.

in pounds per square inch

Mixture 1-2½-5	Age in Days 50	 80
Table 1	165	194
Table 11.	231	300

There were 58 beams of 1-2-4 mixture. The average proportion of these beams by weight was 1-2.25-4.17. There were 50 beams of 1-2½-5 mixture, and the average proportion of these beams by weight was 1-2.89-5.18. There were 4 beams of 1-1½-3 mixture, and the average proportion of these beams by weight was 1-1.85-3.32. There were 3 beams of 1-3-6 mixture, and the average proportion of these beams by weight was 1-3.15-5.65.

Table 13.

Parts by Weight.

Parts by Volume	Thesis	Comparative Table
1 - 2 - 4	1 - 2.25 - 4.17	1 - 2.52 - 4.18
1 - 2½ - 5	1 - 2.89 - 5.18	
1 - 1½ - 3	1 - 1.85 - 3.32	1 - 1.90 - 3.22
1 - 3 - 6	1 - 3.15 - 5.65	1 - 3.76 - 6.34

The above comparative table was taken from the thesis of Otto A. Dicke, presented at the University of Illinois in 1908. The values of each compare very closely.

From Table 11 the 60-day tests show the following results for moduli of rupture.

1-1½-3 concrete was 97% that of 1-1-2
1-2-4 concrete was 92% that of 1-1-2
1-2½-5 concrete was 78.5% that of 1-1-2
1-3-6 concrete was 76% that of 1-1-2

Percent of cement to aggregate by weight of each concrete

27.2 per cent in 1-1-2 concrete
21.2 per cent in 1-1½-3 concrete
14.7 per cent in 1-2-4 concrete
11.2 per cent in 1-2½-5 concrete
10.1 per cent in 1-3-6 concrete
6.9 per cent in 1-4-8 concrete
5.9 per cent in 1-5-10 concrete

Taking the amount of cement in the 1-1-2 concrete as unity and the modulus of rupture for 60 day test as 370 lb. per sq. in., the following table, No. 14, was made for comparison.

Table 14.

Mixture by Volume	Cement by Weight	Modulus of Rupture lb. per sq. in. times ratio of cement	Actual Modulus of Rupture lb. per sq. in.
1-1-2	1.00	370 x 1 = 370	370
1-1½-3	.780	370 x .78 = 288	359
1-2-4	.540	370 x .54 = 200	341
1-2½-5	.410	370 x .41 = 152	290
1-3-6	.371	370 x .371 = 137	282

Taking 370 lb. per sq. in. as the actual modulus of rupture of the 1-1-2 mixture, the next to the last column would give the moduli of rupture of each mixture if made under exactly the same conditions.

In only one test was a deflectometer placed on the beam and in this case several readings were taken before failure occurred, showing a small deflection even on such short spans. Generally, only maximum loads were recorded.

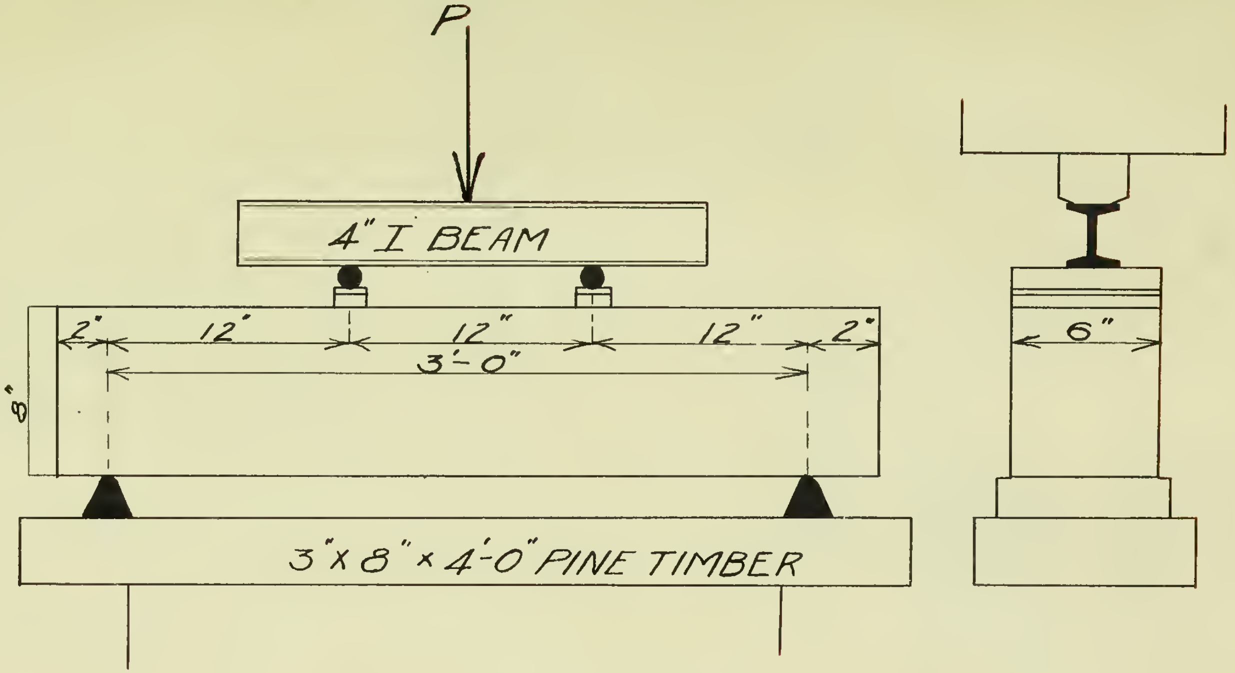
Plate No. 3 shows the Load-deflection Diagram for beam No. 1412 on which a deflectometer was placed.

Description of Figure 1.

The loading was applied at the center of a 4-in. I-beam which rested on $\frac{3}{4}$-in. iron rollers placed at the 1/3 points of the beam. In all cases a strip of rubber belting was placed between the rollers and the beam which served as a cushion, thereby decreasing the rate of loading and also taking up any shocks that might occur.

The support of the beam was on a 3-in. by 8-in. by 4 ft. pine timber which rested upon the bed of the machine. The beam rested on two supports, the tops of which were curved so the beam could deflect with a constant span of 3 ft.

FIG 1.


P
4" I BEAM
2"
12"
12"
12"
2"
3'-0"
8"
6"
3"x 8" x 4'-0" PINE TIMBER

PART 5.

CONCLUSION.

Concrete increases with age for an indefinite period but the rate of increase is much more rapid up to about 60 or 80 days.

The richer mixtures give the greatest modulus of rupture.

The strength of plain concrete is also governed by the quality of cement in unit volume of concrete.

The consistency which will produce the densest concrete will result in the greatest ultimate strength. This is not always desirable when the cost of the concrete is taken into consideration. A cheaper mixture may be a more economical one.

It is often desirable to test concrete on work where available testing machinery is lacking. The compression test is the one most often resorted to but the testing machine required for this is very seldom at the place of construction. If the relation between the crushing strength and flexural strength can be established, the machinery needed for the latter can easily be made with very small cost and a desired efficiency.

A small control beam could be made and tested by applying the load with lever arms and weights or in any other simple and equally cheap way as the operator could devise.

Beam No.	Age in days	Ultimate Load. lb.	Mixture by Volume.	Mixture by Weight	Modulus of Rupture lb. per sq. in.
C1		2450			240
C2		2000			197
3	80	2940	1–2–4	1–2.4–4.1	286
4	80	2710	"	1–2.5–4.2	264
6	79	3450	"	1–2.5–4.2	334
9	89	3950	"	1–1.2–2.1	381
10	89	3570	"	1–2.5–4.2	345
12	88	4100	"	1–2.4–5	394
14	86	4800	"	1–2.4–4.3	460
16	89	3880	"	1–2.5–4.4	374
17	88	4530	"	1–2.5–4.4	435
20	90	3700	"	1–2.6–4.2	357
21	93	3900	"	1–2.5–4.4	376
22	106	2510	"	1–1.2–2	248
23	93	4520	"	1–2.6–4.4	434
24	91	3360	"	1–2.5–2.9	325
26	86	3400	"	1–2.5–4.3	329
28	86	3440	"	1–2.5–4.2	332
30	75	3920	"	1–2.5–4.3	378
32	80	3060	"	1–2.6–4.3	297
33	82	3890	"	1–1.5–2.0	375
36	87	3620	"	1–2.4–4.4	342
37	77	2990	"	1–2.4–3.7	291
38	77	3510	"	1–213–4.2	339
39	76	4360	"	1–2.3–4.2	419
41	76	2890	"	1–2.4–4.3	281
43	77	3070	"	1–2.3–4.3	300
45	71	2090	"	1–2.2–4.1	206
46	79	–	"	1–2.3–4.1	366
48	75	3520	"	1–2.4–4.4	342
50	69	2330	"	1–2.4–4.2	229
52	58	3800	"	1–2.3–4.1	366
54	63	3310	"	1–2.2–4.1	321
56	63	4400	"	1–2.2–4.0	423
58	58	2850	"	1–2.4–4.1	277
62	18	920	"	–	97
64	67	3580	"	1–2.4–4.2	346
66	59	2630	"	–	257
68	56	3000	"	–	292
69	56	2540	"	–	248
70	52	3380	"	–	327
71	61	3200	"	–	310
73	55	2870	"	–	279
75	54	2550	"	–	249

80	69	2730	1-2-4	1-2.3-3.7	266
82	69	3170	"	1-2.5-4.4	308
84	64	2820	"	1-1.2-4.2	285
86	70	2160	"	1-1.8-3.3	213
88	76	1350	"	1-2.3-4.3	137
90	100	1640	"	1-2.3-4.1	160
92	100	1650	"	1-2.4-4.2	165
95	97	1860	"	1-2.4-4.2	185
96	97	1350	"	1-2.4-4.2	137
98	96	2110	"	1-2.3-4.2	208
100	96	1940	"	1-2.3-4.1	192
344.1		5810			555
337.2a		4340			415
337.1		6160			588
102	67	3370	"	1-2.3-4.2	326
104	67	2940	"	1-2.3-4.2	286
106	66	2760	"	1-1.2-4.3	269
108	66	3190	"	1-2.3-4.2	309
110	67	3370	"	1-2.3-4.2	326.
112	49	2850	"		268
127	30	2490	1-2½-5		244
136	74	2990	1-2-4		290
129	74	2700	"		263
202	71	2450	"	1-2.3-4.3	240
211	64	2610	"	1-2.4-4.2	255
711	64	5060	"	1-2.5-3.9	485
811	63	3500	"	1-2.4-4.1	338
911	65	3890	"	1-2.4-4.3	375
151	43	2680	"		261
1111	66	3880	1-1-2	1-1.5-2	374
1141	64	2270	1-2½-5	1- 3 -5.1	223
1161	60	1500	1-4-8	1- 5 -9	151
1166	65	3480	1-2-1	1-2.3-1.1	337
1171	60	560	1-5-10		63
1181	69	3440	1-2-2		333
1191	64	3110	1-2-3	1-1.8-2.5	306
1201	65	1200	1-2-5	1-2.1-5	123
1211	64	3900	1-2-4	1-2.4-4.3	376
1214	57	3120	"		302
1311	62	3720	1-1½-3	1-1.7-3.3	359
1314	74	4000	"	1-2.2-3-8	386
3512		2400			235
1401	86	4110	"	1-1.8-3.1	396
1402	73	3700	"	1-1.7-3.1	357
1403	78	3200	1-2-4		435
1404	78	3840	"	1-2.4-4.1	389
1405	107	3470	1-2½-5	1-3.2-5.3	336
1406	64	2540	"	1-2.9-4.9	248
1411	58	2900	1-3-6	1-3.1-5.3	282

1411	87	2360	1-2½-5		231
1412	74	1500	"	1-3.1-5.3	151
1414	82	2280	"	1-3.2-5.2	224
1414	120	1850	"	1-3.2-5.2	182
1415	78	2990	"	1- 3 -5.1	295
1416	105	1670	"	1- 3 -5.2	167
1416	69	2180	"	1- 3 -5.2	214
1417	71	3330	"		322
1418	69	2710	"	1-2.9-5.1	264
1421	70	2950	"		287
1422	64	1840	"	1-2.6-5.7	183
1425	87	3100	"		301
1426	64	2810	"	1-3.1-5	274
1429	75	2950	"	1-3.1-5.2	287
1431	105	2910	"	1-3.2-5.5	283
1435	109	2950	"	1-3.1-5.1	287
1436	68	1710	"	1-2.9-5	171
1437	83	2720	"	1-2.8-5.1	265
1439	67	2450	"		240
1447	72	3030	"	1-3.2-5.5	294
1448	58	2890	"	1-2.9-5.4	281
1449	98	3030	"	1-3.3-5.4	294
1451	63	2760	"	1-2.9-5.5	269
1452	60	2450	"		240
1455	104	2540	"	1- 3 -5.2	248
1457	98	2430	"	1- 3 -6	238
1601	69	2450	1-3-6		240
1602	80	2320	"	1-3.2-6	228
1605	67	3100	1-2½-5		301
1606	65	2740	"	1- 3 -5.2	267
1611	69	2800	1-2-4		273
1632	65	2910	1-2½-5	1- 3 -5.2	283
1632	56	2350	"	1- 3 -5.2	231
1636	67	3340	"	1-2.5-4.4	435
1641	81	2810	"	1-2.8-4.9	274
1646	63	2580	"	1-3.1-5-5	252
1652	80	2760	"	1-2.8-5.3	269
1651	61	2670	"		260
1655	72	3530	"		341
1661	68	3150	"		306
1662	86	3360	"	1-2.4-5.2	325
1665	63	3150	"		306
1666	65	2610	"	1-2.8-5	255
1672	86	3250	"	1-2.9-5.1	315
1673	62	2980	"		290
1685	57	2980	"		290
1687	66	2960	"	1-2.9-5	288
1692	60	2310	"	1-2.8-5	227

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